SEMICONDUCTOR DEVICE

BACKGROUND OF THE INVENTION

[0001] A. Field of the Invention

[0002] The present invention relates to semiconductor devices including a reverse blocking semiconductor device and a bidirectional semiconductor device, and more particularly, to trench gate semiconductor devices.

[0003] B. Description of the Related Art

[0004] In recent years, in a power conversion circuit which performs, for example, AC (alternating current)/AC conversion, AC/DC (direct current) conversion, or DC/AC conversion using a semiconductor element, a matrix converter has been known as a direct conversion circuit which can be configured without using a DC smoothing circuit including, for example, an electrolytic capacitor or a DC reactor. Since the matrix converter is used at an AC voltage, a plurality of switching devices forming the matrix converter need to be bidirectional switching devices with bidirectionality which can control a current in the forward direction and the reverse direction. As this type of bidirectional switching device, a bidirectional switching device has been used which is formed by connecting two devices, each of which includes a diode for a reverse breakdown voltage that is connected in series to a general insulated gate bipolar transistor (hereinafter, referred to as an IGBT) in inverse and can control a current in two directions.

[0005] In recent years, a reverse blocking IGBT (RB-IGBT) has been used as the above-mentioned bidirectional switching device in order to reduce the size and weight of a circuit, to increase the efficiency and response of the circuit, and to reduce manufacturing costs. The reason is that, when two reverse blocking IGBTs are connected inversely in parallel, it is possible to form the bidirectional switching device, without using the diode for a reverse breakdown voltage. A bidirectional IGBT has the bidirectional switching device, which is formed by connecting two reverse blocking IGBTs in inverse parallel, as a power chip. Next, the structure of the reverse blocking IGBT according to the related art will be described.

[0006] FIG. **15** is a cross-sectional view schematically illustrating the structure of the reverse blocking IGBT according to the related art. In the reverse blocking IGBT, in general, an active region **110** is provided at the center and a separation portion **130** is provided in the outer circumference of the active region **110** through an edge termination structure region **120**. The separation portion **130** includes a p-type isolation region **31**. The active region **110** is the path of a main current of a vertical IGBT including, for example, an n^- drift region **1**, a p base region **2**, an n^+ emitter region **3**, an emitter electrode **9**, a p collector region **10**, and a collector electrode **11**. The isolation region **31** is a p-type region which is formed so as to extend from the front surface of a semiconductor substrate to the p collector region **10** provided on the rear surface side. The structure of the active region **110** will be described in detail with reference to FIG. **16**.

[0007] FIG. **16** is a cross-sectional view illustrating the detailed structure of the active region in the reverse blocking IGBT according to the related art illustrated in FIG. **15**. The n^- drift region **1** is a silicon substrate produced by a floating zone (FZ) method (hereinafter, referred to as an FZ silicon substrate). In the IGBT using the FZ silicon substrate, a high-concentration semiconductor substrate is not used, unlike in an IGBT using an epitaxial silicon substrate according to the related art. Therefore, for example, the thickness of the silicon substrate can be reduced to about 100 μm when the rated voltage of the IGBT is 600 V and can be reduced to about 180 μm when the rated voltage of the IGBT is 1200 V.

[0008] The p base region **2** is selectively provided in a surface layer of the front surface of the FZ silicon substrate which will be the n^- drift region **1**. The n^+ emitter region **3** and the p body region **4** are selectively provided in a surface layer of the p base region **2** which is close to the front surface of the substrate. A gate electrode **7** which is made of polysilicon is provided on the surface of a portion of the p base region **2** which is interposed between the n^+ emitter region **3** and the n^- drift region **1**, with a gate insulating film **6** interposed therebetween. The emitter electrode **9** comes into ohmic contact with both the surface of the n^+ emitter region **3** and the surface of the p^+ body region **4**. The interlayer insulating film **8** is provided between the gate electrode **7** and the emitter electrode **9** and electrically insulates the gate electrode **7** from the emitter electrode **9**.

[0009] The p collector region **10** and the collector electrode **11** which comes into ohmic contact with the p collector region **10** are provided on the rear surface side of the FZ silicon substrate which will be the n^- drift region **1**. When the rear surface structure of the FZ silicon substrate is formed in this way, the thickness of the p collector region **10** is reduced and the p collector region **10** is controlled to the required low impurity concentration. Therefore, it is possible to reduce the injection efficiency of a minority carrier from the p collector region **10** and to improve transport efficiency. As a result, in the reverse blocking IGBT having the above-mentioned structure, the trade-off relationship between on-voltage characteristics and turn-off loss is improved and it is possible to reduce both the on-voltage and the turn-off loss.

[0010] As this type of reverse blocking IGBT, a reverse blocking IGBT has been proposed in which a p base region is formed in the front surface of a semiconductor substrate, an n^+ emitter region is formed in the p base region, a p^+ isolation region and a p^+ collector region are respectively formed in an outer circumferential portion (the side surface of the substrate) and the rear surface of the semiconductor substrate so as to surround the p base region, and the thickness of the p^+ collector region in the rear surface is about 1 μm (for example, see JP 2002-319676 A).

[0011] In addition, as another reverse blocking IGBT, a high-breakdown-voltage semiconductor device has been proposed in which a single-layered semiconductor substrate has at least pn junctions for forward and reverse breakdown voltages formed on both sides thereof and the breakdown voltage junction termination structure of the two pn junctions is provided on the first main surface of the semiconductor substrate by a separating diffusion region. The single-layered semiconductor substrate includes a region in which an impurity concentration distribution is substantially constant from the first main surface toward the inside or impurity concentration is reduced from the first main surface toward the inside. Therefore, in the reverse blocking IGBT, it is possible to reduce a reverse leakage current, without reducing a reverse breakdown voltage (for example, see JP 2006-080269 A).

[0012] As a reverse blocking IGBT with improved electrical characteristics, the following device has been known. FIG. **17** is a diagram illustrating the electric field intensity distributions of the reverse blocking IGBT according to the related art when a forward voltage is applied and when a reverse voltage is applied. FIG. **17**A illustrates the cross-